High Critical Current Density $YBa_2Cu_3O_{7-\delta}$ Thin Film Growth by Post-Deposition Processing at Low Pressures

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INTRODUCTION

The *ex-situ* syntheses of YBCO films are promising techniques for fabricating YBCO coated conductors. In these processes, physical vapor deposited BaF_2 precursors or metal-organic deposition (MOD) trifluoroacetate (TFA) precursors are annealed to form epitaxial YBCO films on various substrates [1]-[3]. In recent years, considerable efforts have been devoted to better understanding the reaction mechanism and to optimize the processing [4]-[6]. Among the main issues concerned are film growth rate, large area film processing and property thickness dependence, etc.

According to the effective reaction,

$$1/2\ Y_2O_3 + 2\ BaF_2 + 3/2\ Cu_2O + 2\ H_2O + 1/2\ O_2 \rightarrow YBa_2Cu_3O_{6.0} + 4\ HF$$

the removal of the decomposition product HF is the key factor that limits the film growth rate [7] and especially for large area samples affects the property uniformity [8]. In this study, instead of typical 1 atmosphere total pressure regime we focused on the possibility of fabricating YBCO thin films under low-pressure *ex-situ* processing condition and thereafter the effects of the basic processing parameters on the growth and the properties of the films.

EXPERMENTAL

The precursor films with thickness ranging from 0.14μm to 1.04μm were deposited on (100) $SrTiO_3$ substrates by e-beam co-evaporation of Y, BaF_2 and Cu at room temperature. The compositions of the precursor films were determined by Rutherford backscattering spectroscopy (RBS), and the final thickness was measured using a profilometer. Post-deposition anneals were carried out in an induction vacuum furnace system in which P_{O2} (ranging from 2mTorr to 40mTorr) and P_{H2O} (ranging from 0.02mTorr to 8mTorr) were carefully controlled. The annealing temperature was fixed at 730°C. Annealing times varied from 45min to 180min depending on film thickness. X-ray diffraction and scanning electron microscopy (SEM) were used for characterizing the YBCO films obtained. The superconducting properties were measured using a standard four-probe electrical method.

RESULTS AND DISCUSSION

Fig. 1 shows a typical X-ray diffraction θ-2θ scan pattern obtained from a 0.34μm thick sample that was annealed under P_{O2}=10mTorr and P_{H2O}=0.1mTorr. Apparently, even at this low oxygen pressure *c*-axis oriented YBCO film can be formed. XRD examination of other samples

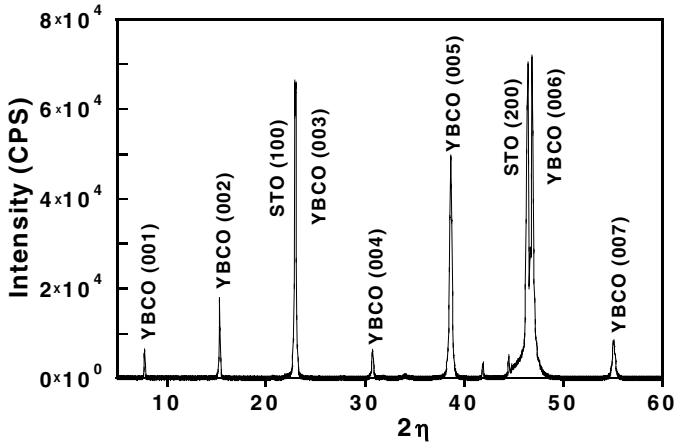

Figure 1. XRD θ-2θ scan for a 0.34μm thick sample annealed under P_{O2}=10mTorr and P_{H2O}=0.1mTorr.

indicated that there is no appreciable difference in the phase composition and YBCO orientation as P_{O2} is varied from 10mTorr to 40mTorr, with P_{H2O} fixed at 0.1mTorr. However, when P_{O2} was lowered to 2mTorr, very little YBCO formed after a 90 min anneal.

Shown in Fig. 2 (a) is the resistive superconducting transition of a film processed at P_{O2}=20mTorr. It can be seen that the transition is sharp and the T_{co} is near 90K. Fig. 2 (b) compares the magnetic field dependence of J_c values at 77K for two 0.34μm thick samples, one was annealed at P_{O2}=40mTorr and the other under typical 1 atm. total pressure condition. The properties are comparable to within usual variations. J_c at self-field for the sample annealed under low pressure is about 3.6MA/cm^2. As the magnetic field increased, the decline in J_c is somewhat less than that of the normal pressure annealed sample, and the irreversibility field, H_{irr},

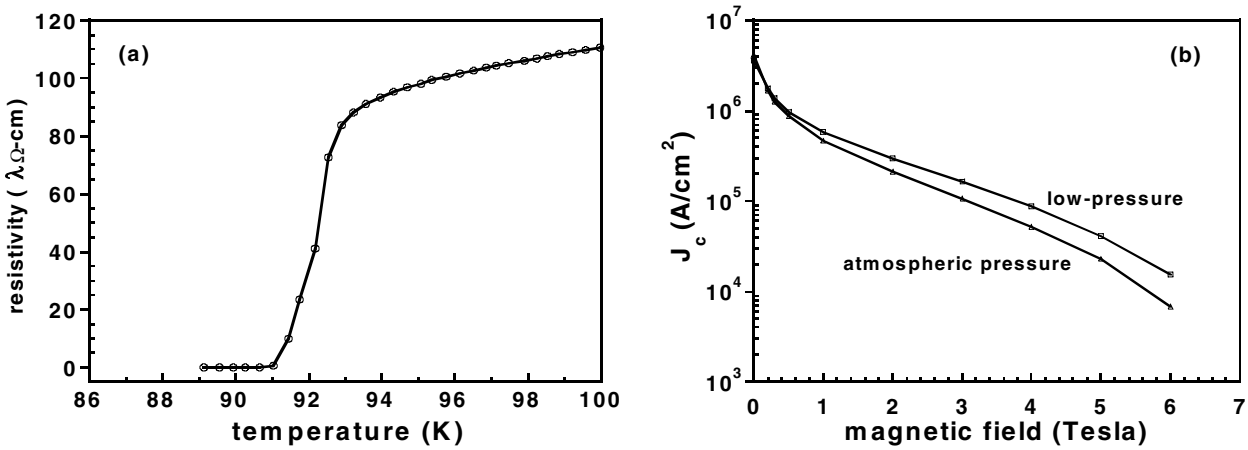

Figure 2. (a) Resistivity versus temperature for a 0.14μm thick film annealed at P_{O2}=20mTorr. (b) Magnetic field dependence of transport J_c at 77K for two 0.34μm thick films. One was annealed at P_{O2}=40mTorr, and the other at P_{O2}=200mTorr in 1 atm. of carrier gas.

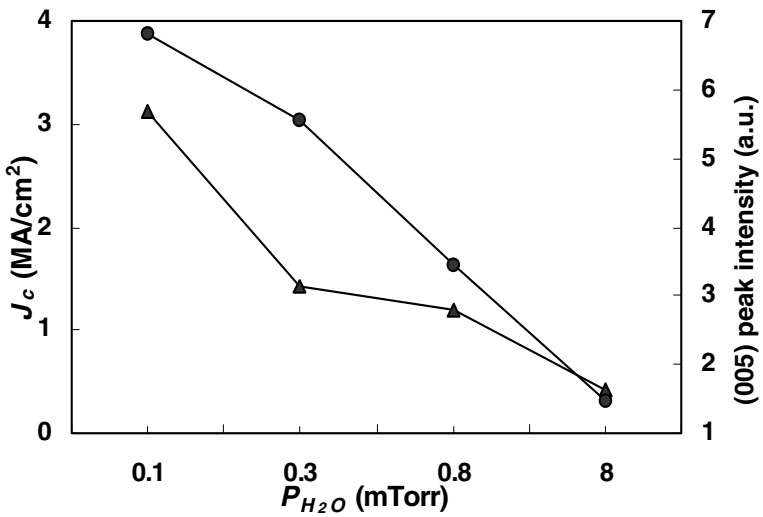

Figure 3. The dependence of J_c and the XRD θ-2θ YBCO (005) peak intensities on the water vapor partial pressure, for 0.34μm thick films processed at P_{O2}=40mTorr.

is about 7.3 Tesla, which implies the low-pressure annealed film may have stronger flux pinning. Measurement of a 1.04μm thick sample gave 77K J_c values of 1.45MA/cm^2 at self-field and 0.2MA/cm^2 at 1 Tesla.

To investigate the effect of P_{H2O} on YBCO formation, different P_{H2O} values ranging from 0.02mTorr to 8mTorr were used with P_{O2} fixed at 40mTorr. The XRD results indicated that YBCO was formed with complete *c*-axis orientation only at P_{H2O}=0.1mTorr. For all anneals with P_{H2O}>0.1mTorr, certain amount of *a*-axis and randomly oriented YBCO appeared along with the predominant *c*-axis YBCO. As P_{H2O} increases, the intensities of *a*-axis (*h00*) peaks and random crystalline peaks in the XRD θ-2θ scan pattern increased while the intensities of *c*-axis YBCO (00l) peaks decreased. The relationship between the intensities of YBCO (005) peaks and the water partial pressures are shown in figure 3. Also shown is the P_{H2O} dependence of J_c values at 77K and self-field.

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